Technical Memorandum TM-80-23

ANTHROPOMETRIC DATA REDUCTION USING FACTOR ANALYSIS AND STEPWISE REGRESSION

(Naval Air Development Center Program Element 62757N/F55-525/WF55-525-000/ZH302)

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(Contract N63126-77-M-0154)

1 July 1980

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(This report was previously published as a *Biotechnology Institute Report* at Texas Tech University and is reprinted in this technical memorandum to meet the requirements of Naval Air Development Center Program Element 62757N/F55-525/WF55-525-000/ZH302.)

PACIFIC MISSILE TEST CENTER

Point Mugu, California 93042

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Technical Memorandum TM-80-23

Published by . . . . . Technical Information Division
Photography and Technical Information Department
Overall classification . . . . . UNCLASSIFIED
First printing . . . . . 155 copies

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SUMMARY

A two-phase approach using factor analysis and stepwise regression was used to identify the most important subset of anthropometric variables from the 1967 survey of USAF flying personnel. Factor analysis by groups was used initially to identify a subset of variables which explain the most variation within the population. Factors identified in the initial analysis were subsequently varimax rotated. Of 185 variables, 32 were selected in this way. In phase 2, stepwise regression is used to regress the remaining variables on the set identified in phase 1. In this way, the variables not selected as most important can be predicted based on the selected subset. The necessary prediction equations, as well as quality of fit indicators, are given. In all, 32 variables are identified as being the most useful subset for explaining the total variance of all 185 variables. This represents a significant reduction in the amount of data which must be collected during an anthropometric survey.

The work was performed under Naval Air Development Center Program Element 62757N/F55-525/WF55-525-000/ZH302.

Publication UNCLASSIFIED.

INTRODUCTION

This study was based on anthropometric measurements of 185 variables performed on a group of 2,420 U.S. Air Force personnel (Clauser, Alexander, and Kennedy; 1967).[1] The objective was to extract from these 185 variables a more limited set that can collectively account for most or all of the remaining variables. These "more important" variables can be used, cost effectively, to predict and quantify those not measured in future investigations. Since the data collection was performed on pre-selected Air Force personnel, the data can be regarded only as representing a U.S. male military population.

This work was performed under Naval Air Development Center Program Element 62757N/F55-525/WF55-525-000/ZH302.

METHOD

In the survey by Clauser, Alexander, and Kennedy, (1967), 204 anthropometric attributes were selected and measured on 2,420 male subjects. In this study, 185 variables were retained and further studied for the sake of homogeneity within each set of variables. The appendix contains abbreviated titles of the variables by variable numbers. Throughout this report, variable numbers will be used to provide for tabulation of results.

As the first step in this study, all the variables measuring the same bodily attribute or belonging to the same body organ were identified and collected in groups signifying that attribute or organ. For instance, all skinfold measurement variables and all head measurement variables were separated from the reamining variables and were given appropriately-designated group labels.

The next step consisted of separate factor analysis by groups on each individual set of variables. The goal was to ascertain whether or not some underlying pattern of relationship exists so that the data could be "reduced" to a smaller set of factors or components and used as source variables for the observed interrelationships in the data. The factors clearly indicate the apparent "dimension" within the particular set of anthropometric variables, thus enabling the analyst to determine how many of the variables in that set possess the quality reflecting the dimension, how many do not, and which therefore are unique.

[1]Clauser, C. E., M. Alexander, K. W. Kennedy (1967). *"USAF Anthropometry of Flying Personnel – 1967,"* Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

The loadings of variables upon the factors are considered correlations between that variable and the factors and the factors and the square of these correlations are indications of the variance of each variable that is explained by the particular factor. Therefore, if many variables load rather heavily on one factor (have high correlations with that factor), it seemed reasonable to select from these variables the one with the highest correlation with the factor and to eliminate the rest. The same method of data reduction was followed for the remaining sets of variables. Exactly the same number of variables was retained as the number of factors for all groups combined.

To provide the user with a means of predicting the "less important" variables from the selected ones, stepwise regression analysis was performed on every group. The regression coefficients and the squared multiple correlations (R^2 values) were recorded as an indication of the amount of variance of the dependent variable explained collectively by all independent variables already existing in the regression model.

DISCUSSION

Initially, the 185 variables in this study were grouped into ten groups of variables each representing the body organ to which the variables belonged or the body dimension the variables were measuring. These groups were labeled as shown in the following table:

Group Name	Number of Variables
Skinfold – V2 through V11	10
Height – V13 through V38	26
Length – V39 through V49	11
Breadth – V50 through V64	15
Circumference – V66 through V75 and V96 through V112	27
Scrotale – V76 through V95	20
Miscellaneous – V113 through V124	12
Foot – V125 through V133	9
Hand – V134 through V140	7
Head – V141 through V188	48
Total	**185**

The Statistical Analysis System (SAS) programming package was used to perform a separate factor analysis on each group.

The factor procedure, based upon the 2,420 observations, computed the simple statistics (such as the means and the standard deviations) and then, as the first step in factor analysis, generated the appropriate measures of association for each set of variables–the product-moment correlation coefficients. The second step in factor analysis consisted of extracting initial factors; this involved construction of a set of new variables based on the interrelations exhibited in the data. The option chosen here defined the new variables as exact linear transformations of the original data. This approach is also referred to as principle-component analysis. These principle components are actually linear combinations of variables within each group. The first principle component accounts for more of the variance in the data as a whole than any other linear combination of variables. The second component accounts for the most residual variance in the data between components which are orthogonal (uncorrelated) to each other.

As the final step in factor analysis, varimax orthogonal rotational was specified to arrive at the terminal solution and to achieve simpler and theoretically more meaningful factor pattern matrices (Kaiser, 1959).[2] In a rotated orthogonal factor matrix, the loadings or numbers in a row represent regression coefficients of factors to describe a given variable. They also represent the correlation between the factors and the variables. By using the default option, one was specified as the smallest admissible value for an eigenvalue; therefore, any factor having an eigenvalue less than one was not further rotated.

Later, in each group the factor pattern matrices were closely examined and the one variable in each factor with the highest weight or correlation was considered as the best representative of the underlying pattern or dimension expressed by that particular factor. Thus, a total of 32 variables were chosen as the independent variables to be used in the second phase of the study. For this phase of the report, separate regression analysis was performed on the variables chosen earlier as the independent variables and on the remaining ones as the dependent variables in every group. This was done so that the user could predict the "less important" variables if he desired not to measure them directly.

At each step, stepwise regression computes, among other things, the squared multiple correlation (R^2) between the predicted and the predictor variables, the ANOVA table consisting of the regression, error, and the total sum of squares (SS) and the mean squares (MS), the F value (MSregress/MSerror), and finally the "regression table" for the variables in the model at that step. The "regression table" contains the regression coefficient of the independent variables together with the value for the intercept so that an equation can be written at each step to quantify the dependent variable. Given a dependent variable and a collection of independent variables, a maximum R^2 improvement technique was specified to be applied on the data. This technique does not settle on a single model. Instead, it looks for the "best" variable model (one, two, or more), with "best" meaning that particular model that produces the highest R^2 statistics. When the first variable is thus chosen, the second candidate is added to the model if and only if it would yield the greatest increase in R^2. Once a two-variable model is established, comparisons are then made between each of the variables in the model and each variable not in the model to ascertain whether or not, for each comparison, the removal of the variable in the model and its replacement with the presently excluded variable would increase R^2. After all the possible comparisons are made, the switch which brings about the largest increase in R^2 is made. This same process is then repeated many times until the procedure finds that no switch could increase R^2. This model is therefore considered as the "best" two-variable model the technique can find. This process of comparing-and-switching is again performed on the next variable until the "best" three-variable model is discovered, etc.

As mentioned earlier, the value of the square of the multiple correlation coefficient R^2 multiplied by 100.0 represents the percentage of the variance of the dependent variable explained collectively by the independent variables in the model. Obviously, the resulting product indicates the degree of the validity of the prediction.

Tables 1 through 10 provide quick summaries of the steps followed for each set of variables involved. Each table can be divided into two parts. The first part establishes the results obtained using the factor analysis and the second part gives the results using the regression analysis. The rotated factor loadings of the variables are listed under headings Factor 1, Factor 2, etc. Each underlined variable at the top of a table represents the variable with the highest loading on a particular factor and thus is used later as an independent variable. The commonalities of the variables are also listed in a special column.

[2]Kaiser, H. F. *Computer Program for Varimax Rotation in Factor Analysis Educational and Psychological Measurement,* Vol. 19, 1959, pp. 413–420.

Table 1. Factor Analysis and Regression Results for the Skinfold Group.

Variable	Factor 1	Intercept	*V6*	R^2	Standard Error of Estimate	Estimated Commonalities
V6*	*.88405*					.783246
V2	n.a.	145.6833	2.3128	.3747	16.9604	n.a.
V3	.86014	4.7669	.7372	.6183	3.2882	.739869
V4	.81900	6.0244	.5571	.3808	4.0327	.671824
V5	.86012	2.4671	.9226	.6111	4.1776	.740468
V7	.87388	7.2410	1.5705	.5732	7.6935	.776627
V8	.68975	4.5159	.2328	.3282	1.8910	.478106
V9	.88290	55.2675	6.9386	.6361	29.7903	.779619
V10	.84074	64.3713	4.8662	.4060	33.4111	.709422
V11	.87611	78.2476	13.6053	.5550	69.1505	.780034

*Variable selected as most useful in explaining the variation of all variables in the group.

Table 2. Factor Analysis and Regression Results for the Height Group.

Variable	Factor 1	Factor 2	Intercept	*V25*	*V35*	R^2	Standard Error of Estimate	Variable	Estimated Commonalities
*V25**	*.95595*	*.19175*							*.950608*
*V35**	*.21296*	*.92763*						*V35*	*.905855*
V14	.83695	.50748	199.8394	1.114105	.683192	.901534	18.2834	V14	.958027
V15	.81382	.54920	107.6764	1.035667	.826087	.92031	16.2513	V15	.963922
V16	.73438	.62459	81.157744	.7216143	.747619	.850522	17.6778	V16	.929435
V17	.62304	.66154	35.25919	.509299	.683625	.71573	21.0077	V17	.825804
V18	.54061	.67260	-23.3338	.387179	.624128	.62762	21.4563	V18	.744643
V19	.83421	.50423	218.07171	1.047783	.628992	.883454	18.8040	V19	.950153
V20	.83897	.47487	131.90426	1.016968	.5497252	.878660	18.2503	V20	.929372
V21	.90815	.32267	84.576888	1.031245	.235240	.883863	16.1006	V21	.928850
V22	.93415	.28409	93.49052	1.087928	.1893101	.916098	13.9247	V22	.953345
V23	.94265	.20136	31.197635	1.049231	.0307678	.934342	11.2449	V23	.929137
V24	.94267	.22385	72.149261	1.0112341	.077253	.90492	13.4384	V24	.938741
V26	.93112	.18145	60.74834	.9677095	.008209	.87706	14.5602	V26	.899904
V27	.93057	.20666	38.00464	.5712546	.0405924	.836129	10.3518	V27	.908672
V28	.93492	.21218	14.594384	.5578760	.04806992	.849176	9.6683	V28	.919095
V29	.91999	.20015	5.973695	.503036	.0403948	.840686	8.9888	V29	.886447
V30	.84070	.16296	-24.54131	.4491585	.0257556	.677647	12.6282	V30	.733335
V31	.54412	.06280	26.98080	.142826	-.009262	.2401966	10.0090	V31	.300008
V32	.32742	.84775	314.84749	.136420	.829358	.685612	17.8184	V32	.825884
V33	.29331	.83249	254.1605	.11132131	.761728	.62443	18.5021	V33	.779070
V34	.25646	.92567	62.17819	.0413861	.9011831	.929013	7.3045	V34	.922643
V36	-.27949	.88089	-42.4059	-.30709	.889633	.810214	11.3589	V36	.854080
V37	.92457	.25795	58.4307	.5487167	.088637	.85745	9.4235	V37	.921374
V38	.90996	.18900	15.85845	.499819	.025774	.8191098	9.5583	V38	.863741
V13	n.a.	n.a.	382.2513	1.14209	.76128	.76984	21.9818	V13	n.a.

*Variable selected as most useful in explaining the variation of all variables in the group.

Table 3. Factor Analysis and Regression Results for the Length Group.

Variable	Factor	Intercept	*V42*	R^2	Standard Error of Estimate	Variable	Estimated Commonalities
*V42**	*.88800*					*V42*	*.788543*
V39	.81233	207.9989	1.10165	.487866	19.3435	V39	.659874
V40	.74665	171.9284	.92300	.376227	20.3676	V40	.557483
V41	.60132	-6.06552	.545571	.386361	11.7831	V41	.361590
V43	.86828	5.02738	.902462	.827579	7.0594	V43	.753908
V44	.87598	98.6673	.55988	.461871	10.3570	V44	.767344
V45	.86091	63.75189	.570490	.472384	10.3326	V45	.741172
V46	.86675	123.4830	.635792	.453603	11.9586	V46	.751262
V47	.81107	239.6201	1.56739	.455095	29.3925	V47	.657830
V48	.76966	294.5583	1.672711	.403722	34.8380	V48	.592375
V49	.86516	68.98046	1.158272	.598545	16.2566	V49	.748508

*Variable selected as most useful in explaining the variation of all variables in the group.

Table 4. Factor Analysis and Regression Results for the Breadth Group.

Variable	*Factor 1*	*Factor 2*	*Factor 3*	Intercept	*V53*	*V61*	*V50*	R^2	Standard Error of Estimate	Estimated Commonalities
*V50**	*-.03990*	*.23228*	*.86256*							.799555
*V53**	*.85305*	*.22690*	*.32867*							.887206
*V61**	*.29147*	*.82489*	*.14752*							.787169
V51	.48343	.21075	.79353	26.6194	.56895	.281710	.617699	.704766	13.9431	.907801
V52	.58983	.15587	.62746	41.4396	.59432	.019852	.246566	.60354	13.3380	.765894
V54	.68032	.26848	.21949	40.11862	.58545	.43458	.03578	.55709	13.6167	.583085
V55	.71631	.40769	.23612	75.91889	.49522	1.05152	.04589	.63489	11.3963	.735068
V56	.78606	.34998	.24513	53.60251	.69340	1.02538	.018475	.70378	12.5319	.800470
V57	.05057	.79614	.19172	25.5562	.010034	.350567	.017788	.266707	3.0877	.673151
V58	.05734	.81155	.19142	25.3156	.0089114	.3598938	.0172637	.2895996	2.9482	.698541
V59	.54530	.18266	.55557	113.12896	.901741	.700672	.199224	.429957	28.5898	.639383
V60	.28755	.82189	.14898	2.6671106	.002432	.955720	.002778	.939676	1.10464	.780389
V62	.72044	.18326	.32727	45.990397	.572798	.115681	.025457	.535050	13.1620	.659725
V63	.82916	.09937	.26426	12.782719	.761252	-.214512	-.009940	.658214	12.7611	.767220
V64	.81452	.17461	.29619	3.371041	.66843	.239466	.013620	.653323	12.0964	.781664

*Variable selected as most useful in explaining the variation of all variables in the group.

Table 5. Factor Analysis and Regression Results for the Circumference Group.

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Intercept	*V70*	*V75*	*V100*	*V111*	R^2	Standard Error of Estimate	Estimated Commonalities
*V70**	*.75040*	*.16780*	*.29315*	*.45345*								*.882808*
*V75**	*.19751*	*.20760*	*.21349*	*.84288*								*.838124*
*V100**	*.28731*	*.29131*	*.82019*	*.23004*								*.893047*
*V111**	*.20625*	*.81786*	*.29821*	*.29404*								*.886818*
V66	.47606	.49269	.13155	.36562	123.8807	.10158	.02378	.00965	.43193	.52233	13.2108	.620354
V67	.59282	.46928	.27492	.35585	258.9444	.30958	.09517	.39978	1.15759	.663492	33.7857	.773873
V68	.64673	.44075	.23209	.34772	116.30409	.368388	.07868	.36230	1.08131	.64785	36.0463	.787294
V69	.69073	.37983	.23587	.38049	72.73533	.50281	.06573	.287127	.87173	.71287	34.0725	.821790
V71	.74792	.17243	.26977	.42149	31.74850	.960910	-.03578	.080857	.09470	.909882	22.5330	.839550
V72	.59022	.20885	.49310	.52342	61.89112	.406400	.182048	.592557	.182227	.831442	22.6530	.909089
V73	.59972	.17510	.44346	.52497	34.84925	.572310	.18085	.55311	.143592	.81071	29.3780	.862569
V74	.26784	.23346	.26632	.82194	131.72944	.134310	.800103	.209481	.211019	.86227	26.5974	.872754
V96	.60245	.22010	.57280	.34475	-98.97408	.262812	.07698	.758331	.170179	.739857	22.6457	.858350
V97	.60871	.24235	.57048	.35564	-94.98747	.264433	.06838	.705934	.232476	.7711611	20.4477	.881194
V98	.29924	.26756	.63779	.51485	31.04771	.071431	.06579	.380355	.153031	.703635	11.3011	.832983
V99	.31508	.27022	.62595	.51763	23.6989	.07043	.071195	.397365	.151068	.714621	11.3510	.832045
V101	.28782	.29166	.80711	.24244	4.40589	.008188	.008236	.897662	.035533	.921966	6.2325	.878105
V102	.06672	.27540	.77280	.34470	24.99846	-.009985	.027729	.399094	.049388	.654043	7.4363	.796337
V103	.41514	.49030	.20980	.42744	58.38814	.118734	.071366	.055495	.622937	.549436	18.7240	.639458
V104	.57551	.59379	.42010	.16359	-55.64060	.113029	-.005332	.234600	.624288	.720614	12.3655	.887043
V105	.62772	.53496	.43136	.14685	-41.75674	.131073	-.00933	.251379	.512069	.702339	12.7762	.887850
V106	.50680	.66565	.40908	.13737	-33.11534	.076661	-.00475	.209744	.749401	.708252	12.2138	.886142
V107	.56712	.58747	.41450	.13321	-20.37647	.097664	-.001526	.220996	.592254	.667593	12.9620	.856295
V108	.28102	.71118	.35624	.37671	15.354242	.028958	.024484	.071241	.5710134	.762559	6.98896	.853565
V109	.09004	.77862	.15902	.32828	21.490861	-.010249	.0214393	-.0794508	.990526	.733567	9.01926	.747411
V110	.29958	.73493	.37885	.33999	10.377617	.027422	.014613	.0851286	.644771	.835568	5.92870	.888988
V112	.01116	.45710	.32549	.47734	49.37962	.0092516	.0251890	.0551670	.1923192	.368663	5.9619	.542863

*Variable selected as most useful in explaining the variation of all variables in the group.

Table 6. Factor Analysis and Regression Results for the Scrotal Group.

Variable	*Factor 1*	*Factor 2*	*Factor 3*	Intercept	*V79*	*V85*	*V86*	R^2	Standard Error of Estimate	Estimated Commonalities
*V79**	*.33685*	*-.84680*	*-.09653*							.839850
*V85**	*.86674*	*.06415*	*-.22677*							.806772
*V86**	*.28598*	*-.03205*	*.82242*							.759182
V76	-.15041	-.66480	-.50791	57.26482	.31054	-.17953	.29004	.377910	16.2170	.722557
V77	.34846	-.69311	.09133	14.86405	.33920	.12795	-.08390	.44781	12.5966	.610171
V78	.04048	-.75156	-.54099	145.71083	.78294	-.18210	.33518	.58304	22.0631	.859145
V80	.01251	-.78935	-.48405	105.03144	.64644	-.18215	.27250	.456116	23.1286	.857529
V81	.30884	-.83225	.01909	-38.18726	.85785	-.00884	-.05098	.729172	15.3963	.788380
V82	.11371	-.75693	-.52040	200.21703	.78348	-.10661	.33016	.51789	25.8939	.856690
V83	.36540	-.81497	-.14710	91.63748	.942081	.03633	.04801	.78851	15.1233	.819332
V84	.85704	-.05727	-.29717	-43.07716	.022399	.76274	.15651	.79850	13.1107	.826106
V87	.32125	-.05609	-.78924	42.60755	.016557	.10147	.81767	.87258	10.4443	.729246
V88	.82310	-.31633	-.34100	196.02860	.42627	.793001	.05843	.65120	23.3896	.893834
V89	.41444	-.27688	-.79393	296.45831	.346389	.101406	.778918	.60336	25.0084	.878748
V90	.83767	-.26375	-.30498	107.18367	.289844	.740683	.039825	.59348	22.7163	.864274
V91	.37828	-.20625	-.81030	225.5744	.184806	.066843	.750114	.551818	24.0552	.842226
V92	.81119	-.31521	-.39138	209.74175	.402310	.803574	.124362	.65851	23.7271	.910561
V93	.82557	-.30851	-.32193	246.20822	.380368	1.01514	-.01669	.75528	20.5620	.880377
V94	.40562	-.26626	-.81637	317.5555	.31059	.13890	.81760	.58586	26.9603	.901880
V95	.42170	-.31175	-.77535	317.4092	.37754	.16809	.72132	.57160	26.8894	.876183

*Variable selected as most useful in explaining the variation of all variables in the group.

Table 7. Factor Analysis and Regression Results for the Miscellaneous Group.

Variable	*Factor 1*	*Factor 2*	*Factor 3*	Intercept	*V114*	*V116*	*V122*	R^2	Standard Error of Estimate	Estimated Commonalities
*V114**	*.80176*	*-.12575*	*-.42020*							.835196
*V116**	*.16788*	*-.81598*	*.10913*							.705920
*V122**	*.06547*	*.30604*	*-.81300*							.758918
V113	.74772	.20711	-.20739	5.61728	.44205	-.09749	.04778	.43855	13.5561	.644983
V115	.75796	-.16793	-.45851	133.17678	1.22239	.07369	.07003	.86084	13.1583	.812937
V117	-.06528	-.44085	-.13799	88.3996	-.05838	.26029	.14228	.07020	16.2905	.217654
V118	.65782	-.17237	-.02035	23.57776	.22419	.06289	.00336	.23336	11.0468	.462848
V119	.18391	-.23059	-.52806	18.09099	.18227	.080063	.058985	.17421	12.0838	.365844
V120	.54595	.43730	.12023	181.0647	.37394	-.33183	.01974	.08549	36.0182	.503749
V121	.61675	.26198	-.42193	154.1136	.55964	-.16986	.33806	.38895	23.6108	.627040
V123	.50519	.36990	-.29977	213.2119	.63247	-.33809	.34196	.22995	38.8883	.481904
V124	.15523	-.16312	-.77406	90.8809	.18499	.39456	.57645	.416246	18.1380	.649869

*Variable selected as most useful in explaining the variation of all variables in the group.

Table 8. Factor Analysis and Regression Results for the Foot Group.

Variable	*Factor 1*	*Factor 2*	Intercept	*V125*	*V133*	R^2	Standard Error of Estimate	Variable	*Estimated Commonalities*
*V125**	*.87954*	*.06878*						*V125*	*.778322*
*V133**	*.20163*	*.84624*						*V133*	*.756780*
V126	.85200	-.04861	9.38098	.72985	-.10224	.80309	4.2252	V126	.728262
V127	.68986	.31363	31.56871	.19269	.16344	.30264	4.1373	V127	.574265
V128	.74898	.38562	69.28722	.48562	.55818	.36081	9.8429	V128	.709677
V129	.77435	.35672	74.75107	.51921	.48791	.38674	9.4548	V129	.726864
V130	.84508	.34053	70.52233	.79949	.61613	.61773	8.7332	V130	.830115
V131	.73404	.23822	17.03733	.16467	.13678	.36753	3.0426	V131	.595561
V132	.14665	.84530	9.78674	.05639	.52934	.36613	4.3074	V132	.736033

*Variable selected as most useful in explaining the variation of all variables in the group.

Table 9. Factor Analysis and Regression Results for the Hand Group.

Variable	*Factor 1*	*Factor 2*	Intercept	*V135*	*V138*	R^2	Standard Error of Estimate	Variable	*Estimated Commonalities*
*V135**	*.14068*	*-.93385*						*V135*	*.891875*
*V138**	*.84407*	*-.35404*						*V138*	*.837790*
V134	.28560	-.89806	24.59772	1.13272	.20332	.75756	4.0410	V134	.888081
V136	.80237	-.36168	7.42437	.07270	.34205	.66716	2.3933	V136	.774614
V137	.74305	-.45101	9.65982	.20957	.32279	.54137	3.3586	V137	.755531
V139	.82399	-.39786	35.23607	.22556	.91804	.72097	5.7108	V139	.837248
V140	.67524	.09712	7.99777	-.00697	.09471	.17394	1.9002	V140	.465379

*Variable selected as most useful in explaining the variation of all variables in the group.

Table 10. Factor Analysis and Regression Results for the Head Group.

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Intercept	V147	Estimated Commonalities
V147*	.01803	.02255	.17348	-.17018	-.12728	-.14774	-.79176	-.30227	.09927	.02604	-.19923			.866404
V155*	-.01883	-.04441	.00360	-.07026	-.04390	-.82326	.08541	-.11806	-.08394	.03503	-.02855			.717287
V156*	.01620	-.02958	.84899	-.00553	-.18311	-.07527	-.07609	.01489	.18340	-.03338	-.05641			.805086
V163*	.04810	-.00389	.08646	.01602	-.85050	-.09525	-.05696	-.09942	.09285	-.00077	-.09378			.773032
V166*	.08154	-.01991	.01580	-.01476	-.09923	-.18802	-.24235	-.62314	.04123	.01227	.11986			.515971
V167*	-.00776	-.02830	-.13184	-.00134	-.03570	-.06756	-.04453	.03873	.92169	-.03128	-.03360			.879183
V168*	-.01691	.02570	.03023	-.84189	-6105E-9	-.20109	-.05389	.14516	.11126	-.08963	-.00964			.795556
V170*	.81387	.02472	-.12401	.01934	-.04110	.08188	.09175	-.05478	-.03525	-.10122	-.06618			.714425
V171*	.42543	.02044	.02175	-.14265	-.03386	.00330	-.06235	.02913	.02255	.00128	-.82297			.885910
V174*	.12979	-.94450	.10831	.08907	-.06475	.05968	.04408	-.03119	-.00692	-.02440	-.03650			.941247
V183*	.10378	.05025	.03813	-.19545	-.03460	-.06378	-.18476	-.11960	.03202	.82444	-.15827			.812425
V141	.10346	-.19620	.47271	-.24041	-.25727	-.09864	-.22970	-.16562	.10139	.58828	-.14580	68.1035	.1575	.864174
V142	.07451	-.38948	.13291	.17356	-.20738	-.10250	-.32777	.35735	-.02501	.42575	-.14808	66.7530	.0935	.697495
V143	-.00800	-.04426	.21570	-.14694	-.48839	.02362	-.12291	-.10960	-.06086	.14375	-.07827	21.3790	.0888	.366839
V144	.33936	-.41207	.65297	-.10427	-.06271	.03996	-.06307	-.06371	.06472	.10840	-.01964	43.8541	.0006	.752111
V145	.03382	-.20633	.41324	-.29553	-.44395	.01890	-.27768	-.25340	.02797	.13028	-.13104	37.0249	.2243	.675530
V169	-.21316	.02264	-.01849	.17296	-.10399	-.11193	-.07903	-.00277	.06288	.07261	-.80991	-4.6920	-.0040	.770981
V172	.33977	.01792	.07218	-.58284	-.02694	-.09378	-.10147	.08968	.08870	-.03862	-.65651	4.5038	.0382	.928900
V173	.11961	-.92980	.08619	.11442	-.04410	.07179	.07191	.00881	-.04039	-.03078	-.02320	11.4064	-.0396	.914815
V175	.19594	-.90519	.18157	.03181	-.05330	.04075	.00820	.01976	-.01066	.00314	-.02868	18.1656	.0036	.897651
V176	.05787	-.94300	.08600	-.14108	-.06926	.00972	.06226	.01851	.00452	-.06665	-.08035	5.7603	-.0205	.939918
V177	.09391	-.94277	.11111	-.17212	-.07285	.01151	.03859	.01274	.00382	-.05555	-.08098	9.9101	-.0038	.956359
V178	.16257	-.90496	.09688	-.16994	-.07166	.00565	.03283	-.01392	.01649	-.04360	-.24105	19.1295	-.0048	.950362
V179	.30947	-.77619	.13371	-.23546	-.06121	.00044	-.03958	.01093	.02235	-.02515	-.40322	21.1273	.0494	.940701

*Variable selected as most useful in explaining the variation of all variables in the group.

Table 10. (Continued)

Variable	*Factor 1*	*Factor 2*	*Factor 3*	*Factor 4*	*Factor 5*	*Factor 6*	*Factor 7*	*Factor 8*	*Factor 9*	*Factor 10*	*Factor 11*	Intercept	*V147*	Estimated Commonalities
V180	.33566	-.65524	.37195	-.03700	-.05242	.02199	-.02322	.09763	.01590	.11139	-.03265	30.1155	-.0359	.708749
V181	.11492	-.25462	.01417	-.24626	-.19696	-.06316	-.23801	-.16093	.00143	.79219	-.14557	19.6712	.0703	.912970
V182	.11448	-.16722	-.00163	-.30217	-.18114	-.07788	-.25412	-.12942	-.00314	.80315	-.12446	26.8833	.06119	.913133
V184	.13592	.19262	-.00627	-.36429	-.09315	-.16976	-.37184	-.10582	.02811	.72636	-.04499	49.8586	.1090	.905692
V185	.18034	.28744	-.01751	-.25290	-.06733	-.14010	-.40749	-.11229	.01736	.72886	-.03593	41.8079	.1366	.915062
V186	.24899	.35464	-.01175	-.15131	-.05679	-.13645	-.44135	-.15476	.01417	.68511	-.03338	37.4161	.1887	.922070
V187	.10254	.43937	.07415	-.07699	-.00618	-.15267	-.51758	-.14705	.04514	.58158	.08176	26.5553	.3440	.874794
V188	.15974	.17784	.01782	-.06628	.10155	-.08629	-.00686	.02119	.06731	.78276	-.11759	-7.6990	-.0770	.711184
V146	-.05893	-.01731	.18147	-.17557	-.34855	-.09785	-.71194	-.29038	.08030	.05137	-.08313	31.5544	.5928	.805764
V148	-.05618	.09192	.17272	-.06552	-.06058	-.10457	-.71573	-.18895	.14781	-.01195	-.23759	-8.0959	.9200	.686746
V149	.11274	.02843	.26135	-.17417	.13422	-.05046	.11620	-.35280	.29868	.42260	-.07024	40.4599	.0316	.543429
V150	.08889	-.21337	.01507	-.30333	-.17669	-.05992	-.19765	-.19820	.01167	.76459	-.15520	24.7802	.0580	.86739
V151	.36425	-.30383	.19621	-.19862	-.01176	-.10181	-.49272	-.07114	.06439	.32001	-.26467	42.2470	.2670	.737879
V152	.09908	-.07075	.03305	-.53117	.04248	-.04806	-.02281	-.45100	.04777	.43602	.01149	37.2202	.0654	.698611
V153	.00686	.04851	.01700	-.04322	-.05281	-.74541	-.13398	.06539	.16684	-.00019	-.00304	8.9795	.0271	.613051
V154	-.08188	-.01452	.07746	-.14283	.03629	-.69293	-.08723	-.22885	.21859	.00165	-.14688	9.2457	.0525	.644128
V157	-.01490	-.03018	.44214	-.05711	-.51873	-.01419	-.18961	-.26841	.08638	-.09602	-.11243	22.0178	.0822	.606475
V158	-.13083	.14275	.66130	-.16852	-.16064	-.18781	-.22551	-.23032	.24270	-.07811	-.06924	11.0815	.1230	.737988
V159	-.14620	.05585	.69263	-.11864	-.28687	-.08516	-.28111	-.26352	.21169	-.11654	-.14303	10.9489	.1370	835170
V160	-.15745	-.06214	.42017	-.07433	-.06795	.00062	-.14432	-.58716	.02416	-.04095	-.06214	11.6047	.1520	.587040
V161	-.01884	-.00931	.35114	-.09320	-.06055	-.12625	-.02384	-.09926	.83977	-.00173	-.03661	37.6336	.0098	.869012
V162	-.00731	-.05636	.08239	.16889	-.76752	-.10958	-.25594	.16542	.07820	-.01310	-.19179	17.9358	.05067	.775576
V164	.16002	.07592	.07077	-.12912	-.72487	-.03086	.07742	-.22772	.10913	.01304	.02557	-3.7928	.00281	.650024
V165	.12332	.04543	2258E9	.10871	-.19729	-.17321	-.16399	-.60542	.11676	.04218	-.05749	-3.0864	.03422	.510160

Table 10. (Continued)

Variable	V155	V156	V163	V166	V167	V168	V170	V171	V174	V183	R^2	Standard Error of Estimate
V147												
V155												
V156												
V163												
V166												
V167												
V168												
V170												
V171												
V174												
V183												
V141	.1159	1.0643	.2533	.2023	-.0554	.1942	-.0358	**.0999**	.30441	1.19176	.71503	7.6398
V142	.0574	.2455	.4015	-.4078	-.1177	-.2216	-.3573	.2473	.6314	.8010	.2905	14.0136
V143	-.0962	.1617	.5274	.0435	-.1106	-.0307	-.0884	.0932	.0545	.1184	.1778	7.1450
V144	-.3042	1.1763	-.1509	.2026	-.0497	.2738	.1984	.1701	.5772	.2676	.5442	8.5267
V145	-.0456	.4588	.5621	.1747	-.0165	.1692	.0459	.0943	.2061	.2551	.4494	7.4064
V146	-.0185	.1176	.4347	.1000	.0543	.0681	.1175	-.2031	.0326	.1207	**.6585**	5.9975
V148	-.3194	.2007	.0971	-.1817	.1570	-.0143	-.0568	.0428	-.1315	.0479	.5614	10.4716
V149	.1765	.4941	-.3686	.3512	.4797	.1617	.1550	.0386	.0171	.7886	.2108	13.3082
V150	.0645	-.0760	.1125	.0906	-.0430	.0890	-.0335	.0744	.1647	.7153	.6453	4.0206
V151	-.0271	.0842	-.0949	.0415	-.0305	.1858	.0568	.2990	.2628	.3333	.5990	4.8170
V152	.1405	-.083	-.1312	.4170	-.0260	.5965	.0731	-.0158	.1006	.6468	.3307	8.3159
V153	.3749	.0301	.0037	.0213	.1410	.0489	-.0391	.0136	-.0240	-.0011	.2357	2.6329
V154	.6221	.0269	-.0243	.1100	.2388	.1054	-.0985	.0544	-.0115	.0082	.3631	3.4114

Table 10. (Concluded)

Variable	V155	V156	V163	V166	V167	V168	V170	V171	V174	V183	R^2	Standard Error of Estimate
V157	.0144	.2424	.4366	.1103	.0055	-.0247	.0449	-.0015	.0221	-.0345	.4150	3.4925
V158	.1249	.5380	.0871	.0843	.0714	.1167	-.0595	-.0241	-.0657	-.0224	.5244	3.8404
V159	.0151	.4993	.1986	.0731	.0635	.0317	-.0617	.0033	-.0230	-.0434	.5939	3.2922
V160	.0784	.2766	.1253	.2926	-.0669	-.0740	-.0013	-.1190	.0520	.0131	.2453	6.0077
V161	.13057	.5926	.0036	.1649	1.5353	.0865	-.0234	.0025	-.0105	.0338	.6478	4.8040
V162	-.01154	.0658	.8973	-.1023	.0363	-.0881	-.0185	.0497	.0162	-.0266	.5417	3.2920
V164	-.0206	.0253	.4464	.0482	.0177	.0379	.0371	-.0038	-.0099	.0037	.3852	2.1807
V165	.0268	.0195	.10657	.2761	.0453	-.0360	.0099	.0020	-.0101	.0226	.2534	2.5409
V169	.0541	.0072	.0735	-.0013	.0602	-.0802	-.2203	.2959	-.0155	.0121	.3377	2.2504
V172	-.0002	.0405	-.0207	-.0305	.0134	.7715	.0414	.8341	-.0026	.0212	.8614	2.2695
V173	.0055	-.0135	-.0387	.0101	-.0464	-.0251	-.0395	.0301	.9783	-.0342	.9018	3.0463
V175	-.0402	.0805	-.0129	-.0013	-.0524	.1230	.0169	.0278	.7377	.0167	.8185	3.2839
V176	.0471	-.0044	.0122	-.0010	-.0421	.6758	-.0969	.0568	1.099	-.040	.8792	3.8350
V177	.0286	.0197	.0219	-.0119	-.0661	.7066	-.0276	.0460	1.0288	.0030	.9005	3.2381
V178	.0314	.0096	.0249	.0152	-.0272	.6345	.07783	.3026	.9614	.0214	.8804	3.4616
V179	.0136	.0545	-.0260	-.0134	-.0601	.6278	.0748	.7658	.8548	.0391	.8733	3.6434
V180	-.1006	.2387	.0031	-.0110	-.0283	.1773	.0030	.1183	.4215	.1135	.5256	4.2163
V181	.0727	-.0695	.1402	.0398	-.0434	.0213	.0038	.0346	.1969	.7586	.7190	3.5813
V182	.07138	-.0718	.1337	.0326	-.0586	.1202	-.0001	.0258	.1276	.7502	.7014	3.6021
V184	.10395	-.0635	.0799	.0860	-.0419	.3204	.0541	-.0179	-.1343	.7752	.7076	4.0715
V185	.0658	-.0752	.0554	.0689	-.0379	.1272	.1373	-.0308	-.2063	.8005	.7039	4.2855
V186	.0497	-.0673	.0409	.1237	-.0401	-.0696	.2958	-.0437	-.2829	.8168	.7121	4.6145
V187	.04823	.0076	-.0341	.1065	-.0028	-.2612	-.0456	-.2496	-.4475	.7837	.6959	5.7887
V188	.02137	.02653	-.1136	-.0505	.03015	-.0019	.0223	.0274	-.0798	.8261	.6811	3.6763

Using the independent variables selected in the first phase of the study, the intercept and the regression coefficients of the remaining variables on the independent variables are also listed under the appropriate column heading; therefore, a separate regression equation can be written for each dependent variable. The values of R^2 and the standard error of estimate for all the dependent variables are also included in separate columns. For example, consider the hand measurement group consisting of the following variables:

V134 – Hand length
V135 – Palm length
V136 – Hand breadth/metacarpal
V137 – Hand breadth at thumb
V138 – Hand circumference/metacarpal
V139 – Hand circumference round thumb
V140 – Hand thickness/meta-3

The rotated factor pattern matrix for the above variables are as follows:

	Factor 1	**Factor 2**
V134	0.28560	-0.89806
V135	0.14068	*-0.93385*
V136	0.80237	-0.36168
V137	0.74305	-0.45101
V138	*0.84407*	-0.35404
V139	0.82399	-0.39786
V140	0.67524	+0.09712

Based on the loadings of the variables on the two factors above, V135 and V138 were selected to be used as the independent variables to predict and quantify the remaining dependent variables in that group. The list of regression equations of the dependent variables on V135 and V138 together with their squared multiple correlation (R^2) values follow:

V134 = 24.59772 + 1.13272 V135 + .20332 V138, R^2 = .75756
V136 = 7.42437 + .07270 V135 + .34205 V138, R^2 = .66716
V137 = 0.65982 + .20957 V135 + .32279 V138, R^2 = .54137
V139 = 35.23607 + .22556 V135 + .91804 V138, R^2 = .72097
V140 = 7.99777 - .00697 V135 + .09471 V138, R^2 = .17394

RESULTS

Tables 1 through 10 give the results of the factor analysis and regression phases of the study, as exemplified previously, for each of the ten groups of variables. An asterisk (*) is used to indicate those variables selected as most useful in explaining the variation of all variables in that group. These variables were then used to predict the remaining variables in each group. The coefficients in the prediction equations are also given, as indicated in the example above.

In all, 32 variables are identified as being the most useful subset for explaining the total variance of all 185 variables. This represents a significant data reduction. However, it is cautioned that it is not likely that this same subset will be identified if any data reduction criterion other than the one defined here is employed.

REFERENCES

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APPENDIX

LIST OF ANTHROPOMETRIC VARIABLES

Variable No.	Variable Title
1	AGE
2	WEIGHT
3	SKF SUBSCAP≠R-LNGE
4	SKF TRICEPS-LANGE
5	SKF JUX≠NIPPLE-LGE
6	SKF MAL XIPH≠D-LGE
7	SKF SUPRAILIAC-LGE
8	SKF SUPRAPATELLA-L
9	SKF SUBSCAP≠R-HARP
10	SKF TRICEPS-HARP≠N
11	SKF SUPRAILIAC-HPN
12	GRIP STRENGTH
13	HEIGHT (STATURE)
14	CERVICALE HEIGHT
15	ACROMION HEIGHT
16	RADIALE HEIGHT
17	STYLION HEIGHT
18	DACTYLION HEIGHT
19	SUPRASTERNALE HGHT
20	NIPPLE HEIGHT
21	WAIST HT-OMPHALION
22	ILIOCRISTALE HT
23	BUTTOCK HEIGHT
24	TROCHANTERION HGHT
25	GLUTEAL FURROW HGHT
26	CROTCH HEIGHT
27	PATELLA TOP HEIGHT
28	KNEE CIRC HEIGHT
29	FIBULAR HEIGHT
30	CALF HEIGHT
31	ANKLE HEIGHT
32	SITTING HEIGHT
33	EYE HEIGHT/SITTING
34	MIDSHOULDER HT/SIT
35	ACROMION H≠GHT/SIT
36	ELBOW REST HGT/SIT
37	KNEE HEIGHT/SITT≠G
38	POPLITEAL HGHT/SIT
39	BUTTOCK-KNEE LNGTH
40	BUTTOCK-POPLITEAL
41	ACRM-BICEP CIR LVL
42	SHOULDER-ELBOW LTH
43	ACROMION-RADIALE L
44	ELBOW-WRIST LENGTH
45	RADIALE-STYLION LH
46	ELBOW-GRIP LENGTH
47	THUMB-TIP REACH
48	THUMB-TIP R≠CH/XTD
49	SLEEVE INSEAM
50	BIACROMIAL BREADTH
51	BIDELTOID BREADTH
52	CHEST BREADTH
53	WAIST BRDTH-OMPH≠N
54	BICRISTALE BREADTH
55	HIP BREADTH
56	HIP BREADTH SITT≠G
57	ELBOW BRDTH BONE/R
58	ELBOW BRDTH BONE/L
59	F≠ARM-F≠ARM BR≠DTH
60	KNEE BR≠DTH BONE/R

Variable No.	Variable Title
61	KNEE BR≠DTH BONE/L
62	CHEST DEPTH
63	WAIST DEPTH-OMPH≠N
64	BUTTOCK DEPTH
65	THIGH CLEARANCE HT
66	NECK CIRC -MAXIMUM
67	SHOULDER CIRCUM≠CE
68	CHEST CIRC AT SCYE
69	CHEST CIRCUMF≠ENCE
70	WAIST CIR-OMPHAL≠N
71	WAIST CIR-OMPH/SIT
72	BUTTOCK CIRCUMF≠CE
73	BUTTOCK CIRCUM/SIT
74	VERTICAL TRUNK CIR
75	VERT TRUNK CIR/SIT
76	SCROTALE-ANT WAIST
77	SCROTALE-A WAIST/S
78	SCRTL-SUPRASTERNLE
79	SCRTL-SUPRSTRNLE/S
80	SCRTL-ANT SCYE LVL
81	SCRTL-ANT SCYE L/S
82	SCRTL-A MIDSHOULDR
83	SCRTL-A MDSHLDR/S
84	SCROTALE-PST WAIST
85	SCRTL-WAIST OVR BK
86	SCROTALE-P WAIST/S
87	SCRTL-WAIST/BUTT/S
88	SCROTALE-CERVICALE
89	SCROTALE-CERVCLE/S
90	SCRTL-PST SCYE LVL
91	SCRTL-PST SCYE L/S
92	SCRTL-P MIDSHOULDR
93	SCRTL-MDSHLD OVR B
94	SCRTL-P MDSHLDR/S
95	SCRTL-MDSHLD O B/S
96	UPPER THIGH CIRCUM
97	UPPER THIGH C/SIT
98	KNEE CIRCUMFERENCE
99	KNEE CIRCUM≠CE/SIT
100	CALF CIRCUMF/RIGHT
101	CALF CIRCUMF/LEFT
102	ANKLE CIRCUMF≠ENCE
103	SCYE CIRCUMFERENCE
104	BICEPS C-EXTEND/RT
105	BICEPS C-EXTEND/LT
106	BICEPS C-FLEXED/RT
107	BICEPS C-FLEXED/LT
108	ELBOW CIR-EXTENDED
109	ELBOW CIRC-FLEXED
110	LOWER ARM C-EXTEND
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112	WRIST CIRCUMF≠ENCE
113	SLVE L/SPINE-SCYE
114	SLVE L/SPINE-ELBOW
115	SLVE L/SPINE-WRIST
116	ANTERIOR NECK LGTH
117	POSTERIOR NECK LTH
118	SHOULDER LENGTH
119	DELTOID ARC
120	INTERSCYE

Variable No.	Variable Title
121	INTERSCYE MAXIMUM
122	WAIST FRONT-OMPH≠N
123	CROTCH LGTH-OMPH≠N
124	WAIST BACK-OMPHL≠N
125	FOOT LENGTH
126	INSTEP LENGTH
127	FOOT BREADTH
128	BALL-OF-FOOT CIRC
129	INSTEP CIRCUMF≠NCE
130	HEEL CIRCUMFERENCE
131	BI-MALLEOLAR BRDTH
132	LAT≠L MALLEOLUS HT
133	MED≠L MALLEOLUS HT
134	HAND LENGTH
135	PALM LENGTH
136	HAND BR/METACARPLE
137	HAND BRTH AT THUMB
138	HAND C/METACARPALE
139	HAND C ROUND THUMB
140	HAND THICK/META-3
141	HEAD CIRCUMFERENCE
142	SAGITTAL ARC/INION
143	MINIMUM FRONIL ARC
144	BITRAGION-CORONAL
145	BITRAGN-MIN FRNTAL
146	BITRAG≠N-SUBNASALE
147	BITRAGION-MENION
148	BIT-SUBMANDIBULAR
149	BITRAG≠N-POSTERIOR
150	HEAD LENGTH
151	HEAD DIAGNL/MENTON
152	HD DIAG/INION-NOSE
153	EAR BREADTH
154	EAR LENGTH

Variable No.	Variable Title
155	EAR L ABVE TRAGION
156	HEAD BREADTH
157	MAXIMUM FRONTAL BR
158	BITRAGION BREADTH
159	BIZYGOMATIC BR≠DTH
160	BIGONIAL BREADTH
161	EAR-TO-EAR BREADTH
162	BIOCULAR BREADTH
163	INTERPUPILLARY BRD
164	INTEROCULAR BR≠DTH
165	NOSE BREADTH
166	LIP LENGTH
167	EAR PROTRUSION
168	SUBNASALE-NASAL RT
169	PHILTRUM LENGTH
170	LIP-TO-LIP LENGTH
171	MENTON-SUBNASALE L
172	MENTON-NASAL ROOT
173	GLABELLA-TO-VERTEX
174	NASAL ROOT-TO-VRTX
175	XTRNL CANTHUS-VRTX
176	PRONASALE-TO-VRTX
177	SUBNASALE-TO-VRTX
178	STOMION-TO-VERTEX
179	MENTON-TO-VERTEX
180	TRAGION-TO-VERTEX
181	GLABELLA-TO-WALL
182	NASAL ROOT-TO-WALL
183	XTRNL CANTHUS-WALL
184	PRONASALE-TO-WALL
185	SUBNASALE-TO-WALL
186	LIP PROMIN≠CE-WALL
187	CHIN PROMINCE-WALL
188	TRAGION-TO-WALL

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